

DETECTING TOOL ORIENTATION, ALIGNMENT,  
DEPTH, AND LEVELING

20220-99818001

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CLAIM OF PRIORITY

This application claims the benefit of U.S. Provisional Application No. 60/270,733, "Manually Guided, Self-Correcting, Power Tools," filed on February 22, 2001, and U.S. Provisional Application No. 60/271,844, 10 "Manually Guided, Self-Correcting, Power Tools," filed on February 27, 2001, both of which are incorporated herein by reference.

CROSS-REFERENCE TO RELATED APPLICATION

15 This Application is related to the following Application:  
"Tools With Orientation Detection," by Andrew Butler, Christopher A. Tacklind, Lance Reisman, Aragon Burlingham, Dan Adams, Gene Duval, William Scott, Rick Feffer, and Jon Carver, Attorney Docket No. TOOLZ-01056US2, filed the same day as the present application, and incorporated 20 herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

25 The present invention is directed to detecting tool orientation, alignment, depth, and leveling.

Description of the Related Art

30 Tool operators often need to perform precise operations with their tools. Examples of such operations include the following: cutting a surface along a straight line, routing a detailed pattern into a surface, driving nails into a surface in conformance with a predefined pattern or spacing, and drilling a straight hole to a specified depth.

Current tools don't provide efficient mechanisms for aiding operational accuracy. For example, a drill operator has no way of knowing whether the

drill's bit is aligned normal to a work piece surface or the depth of a drill hole. Before drilling holes on a surface it may also be necessary to know whether the surface is level, but a drill doesn't include a mechanism for detecting level. These same problems with alignment, depth, and leveling apply to tools other than drills.

5 In many instances, tool operators need to rely on their own hand-eye coordination to make alignment assessments and adjustments during a tool's operation. No mechanism is provided to conveniently align or assist in the alignment of the tool.

10 Accordingly, there is a need for devices that can be conveniently used in conjunction with a tool to assist with detecting orientation, alignment, depth, and leveling.

#### SUMMARY OF THE INVENTION

15 The present invention, roughly described, pertains to devices used in conjunction with a tool to assist with alignment, depth detection, and leveling. In some embodiments, the tool has the ability to detect its own orientation and make adjustments. Nail guns, jigsaws, circular saws, routers, and drills serve as a partial list of tools in which this functionality is useful.

20 In one embodiment, a tool employs all or some of the following: an alignment detector, a depth detector, and a level detector. The alignment detector provides a laser line grid. When the alignment detector is parallel to a work piece's surface, the grid includes two sets of parallel lines that are perpendicular to each other — forming a tic-tac-toe board pattern that shows 25 a tool user the desired alignment has been reached.

One version of the depth detector employs a set of laser lines. The depth detector emits two sets of parallel laser planes that converge with each other. Two sets of lines are formed when the laser planes impact on a work piece surface. As the depth detector moves closer to the work piece surface, the laser lines from one laser plane set move closer to the lines from the other laser plane set. The spacing between the lines from each laser plane set corresponds to the distance between the depth detector and work piece

surface. Alternate versions of the depth detector employ different laser line patterns.

One implementation of the level detector employs two converging laser planes. The level detector is positioned above a work piece surface, so the 5 planes' line of intersection appears on the surface if the surface is level. If the surface is not level, separate lines from each laser plane appear on the surface — signaling the need for a level adjustment.

A tool with some or all of the above-described detectors may be employed along with a guide system to detect the tool's orientation. In one 10 embodiment, the guide system supplies a guide signal to identify a line on a work piece, such as a wood surface. The tool detects the guide signal and determines the tool's orientation with respect to the line on the work piece. In a further embodiment, the guide system supplies the tool with guide signals that enable the tool to determine its absolute position on the work piece. For 15 example, the tool can employ the guide signals to determine the tool's (x, y) coordinate orientation on a surface.

One example of a guide system is a laser projector that supplies one or multiple laser beams. The tool includes an array of photo diode detectors to detect the positions of the laser beams relative to the tool. The tool 20 determines its orientation, based on the detected laser beam positions. Alternate guide systems include guide wires, track balls, and range finders.

The tool employs its detected orientation to enhance tool performance. In one implementation, the tool adjusts its orientation. For example, a jigsaw 25 rotates its blade after determining that the current orientation will not yield the desired cut. In another implementation, the tool provides a user with steering directions, based on the determined orientation. In one instance, a nail gun employs a set of directional indicators to show a user the necessary movement of the gun to reach a desired target.

In further embodiments, tools make alternate adjustments based on the 30 determined orientation. A router adjusts the vertical displacement of its cutting head, based on the router's orientation on a work piece. A nail gun enables and disables its nail firing mechanism, based on the gun's orientation

on a work piece. Those skilled in the art will recognize that the application of the present invention to nail guns, saws, routers, and drills are only exemplars of the invention's utility. Embodiments of the present invention can be implemented in a variety of tools.

5 The present invention can be accomplished using hardware, software, or a combination of both hardware and software. The software used for the present invention is stored on one or more processor readable storage media including hard disk drives, CD-ROMs, DVDs, optical disks, floppy disks, tape drives, RAM, ROM, memory sticks or other suitable storage devices. In  
10 alternative embodiments, some or all of the software can be replaced by dedicated hardware including custom integrated circuits, gate arrays, FPGAs, PLDs, and special purpose computers.

These and other objects and advantages of the present invention will appear more clearly from the following description.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts a block diagram of a tool in accordance with the present invention.

Figure 2 illustrates a series of operations performed by the tool shown  
20 in Figure 1.

Figure 3 shows a block diagram of a tool operating with a laser system in accordance with the present invention.

Figure 4 depicts a block diagram of a tool operating with a pair of laser systems in accordance with the present invention.

25 Figure 5 shows a block diagram of a tool operating with a pair of guide wires in accordance with the present invention.

Figure 6 illustrates a block diagram of a tool operating with a track ball mechanism in accordance with the present invention.

Figure 7 depicts a block diagram of a tool operating with range finder in  
30 accordance with the present invention.

Figure 8 depicts a nail gun operating with a laser system in accordance with the present invention.

Figure 9 shows a sequence of steps performed by the nail gun shown in Figure 8.

Figure 10 illustrates a nail gun employing a track ball mechanism in accordance with the present invention.

5 Figures 11 and 11A depict a jigsaw operating with a laser system in accordance with the present invention.

Figure 12 illustrates a circular saw operating with a laser system in accordance with the present invention.

10 Figure 13 depicts a router operating with a pair of laser systems in accordance with the present invention.

Figure 14 shows a router operating with a pair of guide wires in accordance with the present invention.

Figure 15 shows a drill, including alignment and depth detectors in accordance with the present invention.

15 Figures 15A and 15B show one embodiment of an alignment detector.

Figure 16 shows one implementation of a depth detector.

Figure 16A illustrates a series of laser patterns provided by the depth detector in Figure 16.

Figure 17 shows an alternate implementation of a depth detector.

20 Figure 17A illustrates a series of laser patterns provided by the depth detector in Figure 17.

Figure 18 shows one embodiment of a level detector.

Figure 18A shows laser patterns provided by the level detector in Figure 18.

25 Figure 19 illustrates hardware employed in a tool in one embodiment of the present invention to carry out sequences of operation described below with reference to Figure 1-14.

#### DETAILED DESCRIPTION

30 A. Tool Architecture and Operation

Figure 1 shows a block diagram of tool 10, which represents one embodiment of the present invention. Nail guns, jigsaws, circular saws, and

routers are non-exhaustive examples of the types of tools that tool 10 can be. The implementation of nail guns, jigsaws, circular saws, and routers in accordance with the present invention are described later in greater detail with reference to Figures 8-14.

5 Tool 10 includes action component 22, which operates on a work piece. Examples of action component 22 include saw blades, router cutting heads, and nail gun firing mechanisms. Component controller 16 is coupled to action component 22 to control the operation of action component 22 — directing the operation of action component 22 in response to an orientation of  
10 tool 10. In alternate implementations, tool 10 does not include component controller 16, since tool 10 does not adjust the orientation of action component 22.

15 Guide detector 12 receives guides from a guide system (not shown) and ascertains the position of the guides relative to tool 10. In one embodiment, guide detector 12 is a pair of photo diode detectors used to detect the position of laser beams from a laser guidance system. Guide detector 12 is coupled to location detector 14 to provide position data reflecting the guide positions. Location detector 14 determines an orientation of tool 10 relative to a work piece on which action component 22 will operate.  
20 Location detector 14 is coupled to component controller 16 to supply information identifying the tool orientation. Controller 16 then uses this orientation information to make adjustments to action component 22, such as changing the orientation or state of component 22. In some embodiments, the orientation information corresponds to tool adjustments that component controller 16 must make.  
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30 Location controller 14 is also coupled to communication port 18 and indicator set 20. Communication port 18 enables location detector 14 to share orientation information with external devices, such as the guide system. Indicator set 20 provides directional signals to tool operators to assist in steering or aiming tool 10. Indicator set 20 is coupled to location detector 14 to receive tool orientation information that controls which indicators are asserted. Alternate implementations of tool 10 include either indicator set 20

or action component 22, but not both. Some versions of tool 10 do not include communication port 18.

5 Applications of the block diagram architecture shown in Figure 1 to specific types of tools, including nail guns, power saws, and routers are described below with reference to Figures 8-14.

10 Figure 2 shows a sequence of operations performed by one version of tool 10. Guide detector 12 receives one or more guide inputs from one or more guide systems, such as a laser beam from a laser system (step 40). Guide detector 12 detects the positions of the guides relative to tool 10 and forwards data identifying the position to location detector 14 (step 42). Location detector 14 employs the position data to determine the orientation of tool 10 with respect to a work piece, such as a piece of wood to be routed by tool 10 (step 44). In order to facilitate the orientation determination by location detector 14, the one or more guide systems have a predefined physical relationship to the work piece. Examples of different guide systems are provided below.

15 By detecting the orientation of tool 10, location detector 14 inherently determines the orientation of action component 22. In this application, the operation of determining the orientation of tool 10 is considered 20 interchangeable with the operation of determining the orientation of action component 22. Action component 22 has a known physical displacement from guide detector 12. When detecting the orientation of tool 10 in one embodiment, location detector 14 determines the orientation of guide detector 12, based on the position data, and applies the known physical displacement 25 to determine the orientation of action component 22.

Location detector 14 determines whether any adjustment needs to be 30 made to tool 10, based on the identified orientation (step 46). Examples of situations where tool adjustments are needed include the following: 1) a jigsaw blade's orientation being out of alignment with a desired cutting line on a work piece, 2) a nail gun's orientation corresponding to a position on a work piece where the gun's firing mechanism should not be enabled, and 3) a

router cutting head's orientation corresponding to a location on a work piece where the head's vertical displacement needs to be adjusted.

If an adjustment is needed, the state of tool 10 is adjusted (step 48). Otherwise, no adjustment is made. In either instance, tool 10 continually

5 repeats the process shown in Figure 2. On example of an adjustment made by tool 10 (step 48) is changing the orientation of action component 48. Component controller 16 recognizes that the orientation of action component 22 needs to be adjusted, based on orientation information supplied by location detector 14. Component controller 16 continues to adjust the orientation of

10 action component 22, until the orientation information from location detector 14 no longer indicates any adjustment is necessary. For example, component controller 16 continues to adjust the orientation of a jigsaw's blade until location detector 16 indicates that the blade is in line with a desired cutting line.

15 Another type of adjustment made by tool 10 (step 48) is altering the state of action component 22, based on orientation information supplied by location detector 14. In this embodiment, location detector 14 recognizes the orientation of tool 10 as corresponding to a desired state of action component 22. Location detector 14 then supplies orientation information to component

20 controller 16 — causing controller 16 to place component 22 in the desired state. For example, component controller 16 enables or disables the firing mechanism of a nail gun, based on the firing mechanism's orientation.

Tool adjustments (step 48) also include asserting and deasserting indicators that direct a tool user's operation of tool 10. Indicator set 20 in tool

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10 responds to the tool orientation provided by location detector 14 to provide the tool's user with proper signaling. For example, in a router indicator set 20 provides directional signals to the tool user — indicating the direction the user should steer the router, based on the router's current orientation on a work piece. A light emitting diode is one type of indicator that can be employed in

30 tool 10.

B. Employing Different Guide Systems

Figure 3 shows tool 10 in use with a single laser system 50 that provides a single laser beam 52 as a guide. Examples of a laser projection systems that can be employed as laser system 50 are described in U.S.

5 Patent and Application Nos. 5,680,208, issued October 21, 1997; 08/953,935, filed October 20, 1997; 5,903,345, issued May 11, 1999; 09/247,750, filed February 9, 1999; 09/571,482, filed May 16, 2000, and 09/928,244, filed August 10, 2001 all of which are included herein by reference.

Laser system 50 can be self-leveling or non-self leveling. The central  
10 axis of laser beam 52 identifies a path on a work piece, such as a cutting line to be followed by a jigsaw's blade. Guide detector 12 receives laser beam 52 and identifies the position of laser beam 52 relative to tool 10. In one implementation, guide detector 12 includes an array of photo diode detectors. The photo diode detectors are arranged so that each photo diode provides the  
15 same signal when tool 10 is oriented with action component 22 in line with the work piece path. When tool 10 is not oriented in this fashion, the photo diode detectors supply unequal signals.

Location detector 14 receives the output of the photo diode detectors. Location detector 14 determines the orientation of tool 10 with respect to the  
20 work piece path, based on the position data supplied as output signals from the photo diodes. If all the signals are equal, location detector 14 determines that tool 10 is oriented so that action component 22 is in line with the desired path on the work piece. If the photo diode signals are not all equal, location detector 14 identifies tool 10 as being offset from the work piece path in a  
25 direction that corresponds to the strongest photo diode signals. For example, if guide detector 12 has two photo diode to detect beam 52, the tool is offset to the right of the work piece path if the right most photo diode detector provides a stronger signal than the other detector.

Those of ordinary skill in the art will recognize that numerous types and  
30 arrangements of laser beam detectors can be employed in guide detector 12 to achieve the above-described operation of tool 10. As shown in Figure 3,

tool 10 does not include communications port 18. In alternate embodiments of a single laser application, communications port 18 is included in tool 10.

Figure 4 shows tool 10 in use with laser systems 60 and 62, which provide laser beams 64 and 66, respectively. Tool 10 employs beams 64 and

5 provide laser beams 64 and 66, respectively. Tool 10 employs beams 64 and 66 to identify the orientation of tool 10 on a work piece in terms of an absolute position, such as an (x,y) coordinate. Laser systems 60 and 62 are the same as laser system 50 in Figure 3. In one embodiment, Laser systems 60 and 62 are rotating laser systems. Laser systems 60 and 62 are positioned so that laser beams 64 and 66 each have a predefined point of origin within a 10 coordinate system covering the work piece. For example, a wooden surface to be routed can be described in terms of a two dimensional orthogonal (x,y) coordinate system that includes the points of origin for laser beams 64 and 68.

Guide detector 12 includes an array of photo diode detectors, as 15 described above with reference to Figure 3. Guide detector 12 detects when tool 10 is oriented in a position where laser beams 64 and 66 each intercept the same predetermined location in the array, such as the array's center. This indication is provided as position data in the form of photo diode signal intensity, as described above for guide detector 12 in Figure 3. Guide 20 detector 12 also determines the time required for laser beams 64 and 66 to each rotate between the predefined location on the photo diode detector array and axis 68 — the axis line passing through the origin points of laser beams 64 and 66. In one version of this embodiment, axis line 68 is parallel to one axis in a two dimensional coordinate system encompassing the work piece 25 and perpendicular to the other axis in the two dimensional coordinate system.

Guide detector 12 passes the time measurements to location detector 14 to serve as position data — identifying the positions of laser beams 64 and 66 relative to tool 10. Location detector 14 uses the time measurements to determine the orientation of tool 10. Location detector 14 determines a (x, y) 30 coordinate for guide detector 12. This coordinate corresponds to a (x, y) coordinate for action component 22, which has a known displacement from guide detector 12.

The (x, y) coordinate of guide detector 12 resides at the intersection of laser beams 64 and 66. Location detector 14 employs the laser rotation times to determine x and y displacements for the lines formed by laser beams 64 and 66. The x and y displacements are then employed by location detector

5 14 to calculate the x, y offset of guide detector 12 from the known x, y coordinates of the origins of laser beams 64 and 66.

In order to determine the x, y displacements from laser beams 64 and 66, location detector 14 employs the following relationships in one embodiment:

10 From the time detections made by guide detector 12, location detector 14 determines the angles in the triangle formed by laser beam 64, laser beam 66, and axis line 68 using the following equations:

$$\theta_{60} = \frac{360^\circ(t_{64})}{t_{60}}$$

$$\theta_{62} = \frac{360^\circ(t_{66})}{t_{62}}$$

wherein:

$\theta_{60}$  is the angle between axis line 68 and laser beam 64 within the triangle formed by laser beam 64, laser beam 62, and axis line 68.

20  $\theta_{62}$  is the angle between axis line 68 and laser beam 66 within the triangle formed by laser beam 64, laser beam 62, and axis line 68.

$t_{60}$  is the time required for laser beam 64 to make a complete revolution.

25  $t_{62}$  is the time required for laser beam 62 to make a complete revolution.

$t_{64}$  is the time required for laser beam 64 to traverse angle  $\theta_{60}$ .

$t_{66}$  is the time required for laser beam 66 to traverse angle  $\theta_{62}$ .

From the law of cosines the lengths of laser beams 64 and 66 can be derived using the following equations:

$$L_{64}^2 = B^2 + L_{66}^2 - 2(B)(L_{66}) \cos \theta_{62}$$

$$L_{66}^2 = B^2 + L_{64}^2 - 2(B)(L_{64}) \cos \theta_{60}$$

wherein:

5  $L_{64}$  is the length of laser beam 64.

$L_{66}$  is the length of laser beam 66.

B is a known distance between the points of origin for laser beam 64 and laser beam 66.

From trigonometry, the x and y displacements of laser beams 64 and 10 66 from their respective points of origin can be found using the following equations, where axis 68 is parallel to the x axis:

$$x_{64} = L_{64} \sin (90^\circ - \theta_{60})$$

$$y_{64} = L_{64} \cos (90^\circ - \theta_{60})$$

$$x_{66} = L_{66} \sin (90^\circ - \theta_{62})$$

15  $y_{66} = L_{66} \cos (90^\circ - \theta_{62})$

wherein:

$x_{64}$  is the x axis displacement from the origin of laser beam 64 to the point where laser beam 64 is incident on guide detector 12.

20  $y_{64}$  is the y axis displacement from the origin of laser beam 64 to the point where laser beam 64 is incident on guide detector 12.

$x_{66}$  is the x axis displacement from the origin of laser beam 66 to the point where laser beam 66 is incident on guide detector 12.

$y_{66}$  is the y axis displacement from the origin of laser beam 66 to the point where laser beam 66 is incident on guide detector 12.

25 In alternate embodiments, location detector 14 includes a look-up table that converts time measurements pairs for laser beams 64 and 66 into (x, y) coordinates.

30 In one implementation, tool 10 receives values for  $t_{64}$ ,  $t_{66}$ , and B from laser systems 60 and 62 via communications port 18. Communication port 18 can communicate with laser systems 60 and 62 using many well-known

communication media and protocols. Example media include radio frequency, infrared and cable signaling. In other implementations, values for  $t_{60}$ ,  $t_{62}$ , and  $B$  are stored in tool 10 — eliminating the need to use communication port 18.

5 In other versions of tool 10, different well-known methods are employed for ascertaining x, y displacements for laser beams 64 and 66.

Figure 5 illustrates tool 10 in use with guide wire systems 80 and 82 to determine the orientation of tool 10. In this embodiment, tool 10 obtains a (x, y) coordinate to serve as the orientation of tool 10. Guide wire system 80

10 anchors guide wire 84, and guide wire system 82 anchors guide wire 86. The anchors reside on axis line 83, which is the same as axis line 68 in Figure 4. The distance  $B$  between the anchor points is known to location detector 14.

Wires 84 and 86 are each coupled to guide detector 12 with a two-spring tension wire real device in guide detector 12. Guide detector 12 has a

15 device to measure the displacement distance of wires 84 and 86. In one implementation, the displacement measuring device is an encoder attached to the real device to detect the extension of wires 84 and 86.

Guide detector 12 supplies the wire lengths to location detector 14 as position data that identifies the position of tool 10 relative to guide wire 20 systems 80 and 82. Location detector 14 determines the orientation of tool 10 using the wire lengths and the trigonometric principles described above with reference to Figure 5. Using the law of cosines, the angles between (1) wire 84 and axis 83 and (2) wire 86 and axis 83 can be found. Once the angles are known, location detector 14 can solve for the x and y displacements of 25 wires 84 and 86 to obtain a coordinate for tool 10.

Figure 6 depicts tool 10 in operation with track ball mechanism 100 serving as a guide system. In one embodiment, track ball mechanism 100 is a well known rolling sensor used in a computer mouse to determine movements. In alternate implementations, optical tracking systems like those 30 used in an optical computer mouse can be employed.

Track ball mechanism 100 is attached to tool 10 and provides information identifying changes in the two dimensional (x, y) orientation of the

track ball. Guide detector 12 receives this information and passes it to location detector 14 as position data identifying the position of track ball mechanism 100. Location detector 14 employs the two dimensional position data to determine a tool orientation. In one embodiment, location detector 14 applies the x, y changes to the tool's prior x, y coordinates.

5       Figure 7 illustrates tool 10 operating with range and angle finder 110 as a guide system. Range and angle finder 110 determines the displacement of tool 10 from finder 110 and communicates the displacement to communication port 18. Those skilled in the art will recognize that a standard  
10 range and angle finder can be employed, such as a range and angle finder employing laser, infra red, or radio frequency signaling. In one implementation, range and angle finder 110 has a rotating range and angle finding signal, while in other embodiments, the range and angle finder signal does not rotate.

15       Location detector 14 receives the displacement information from communications port 18 and determines the orientation of tool 10. In one implementation, range and angle finder 110 supplies the displacement information as a two-dimensional polar coordinate ( $\theta, r$ ). As shown in Figure 7, guide detector 12 is not included in tool 10 in the range and angle finder embodiment, since range and angle finder 110 provides coordinates.  
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The above-described guide systems are not an exhaustive list of guide systems. Those skilled in the art will recognize that numerous alternative guide systems can be employed in embodiments of the present invention.

25       C.     Example Embodiments

The following provides example embodiments of the above-described tool 10.

1.     Nail Gun Embodiments

30       Figure 8 shows nail gun 216 in use with laser system 212 in accordance with the present invention. Nail gun 216 has the functionality and design described above for tool 10 with reference to Figure 3. Laser system

212 operates as described above for laser system 50 in Figure 3. Laser system 212 provides laser beam 218 as a guide signal to nail gun 216. In the embodiment shown in Figure 8, beam 218 reflects off mirror 220, but in alternate implementations laser beam 218 is provided directly to nail gun 216.

5 Photo diode detector array 214 is mounted on the head of a nail gun 216 to operate as guide detector 12. When detector array 214 has a predetermined alignment with laser beam 218 and the nail gun's trigger is squeezed, nail gun 216 automatically fires. When detector array 214 is not properly aligned with laser beam 218, nail gun 216 will not fire. This arrangement allows for nail gun 216 to be fired along a line defined by laser beam 218. Nail gun 216 includes component controller 16 to set the firing state of the nail firing mechanism in gun 216 based on the gun's orientation.

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In an alternate embodiment, nail gun 216 only fires nails when the gun is offset from laser beam 218 — creating a staggered nail pattern that avoids

15 splitting natural material such as a rafter or joist member. In order to further assist tool operators, nail gun 216 includes directional light emitting diodes ("LEDs") 232 on top of the gun to serve as indicator set 20. Nail gun 216 lights a center LED when the gun is directly in line with laser beam 218 and lights either a right or left LED to direct the user to one side of laser beam 218.

20 Figure 9 depicts a series of operation taken by nail gun 216 to create a staggered nail pattern. Photo diode array 214 combines with location detector 14 to determine whether nail gun 216 is oriented in line with the center of laser beam 218 (step 224). Once nail gun 216 is oriented on the center of laser beam 218, indicator set 20 lights a center LED and a right LED (step 225). The right LED shows the tool operator to steer gun 216 to the right.

25 Photo diode array 214 combines with location detector 14 to determine when nail gun 216 is oriented to the right of laser beam 218 in a position for firing (step 227). Once nail gun 216 is in a firing position, component controller 16 enables the gun's firing mechanism, and indicator set 20 deasserts the right LED (step 228). In operation, a user has the nail gun trigger pulled when the firing mechanism is enabled — resulting in a nail being

driven into the work piece. After the nail is fired, component controller 16 disables the nail gun firing mechanism (step 229).

Photo diode array 214 once again combines with location detector 14 to determine whether nail gun 216 is oriented in line with the center of laser beam 218 (step 230). Once nail gun 216 is centered, indicator set 20 lights the center LED and a left LED (step 231). The left LED shows the tool operator to steer gun 216 to the left. Array 214 combines with detector 14 to determine when nail gun 216 is oriented to the left of laser beam 218 in a position for firing (step 232). Once nail gun 216 is in a firing position, 10 component controller 16 enables the gun's firing mechanism, and indicator set 20 deasserts the left LED (step 233). After the nail is fired, component controller 16 disables the nail gun firing mechanism (step 234). The above-described process in Figure 9 is performed repeatedly until all nails are driven into the work piece.

15 In another embodiment, a two-dimensional array of nailing patterns is preprogrammed into nail gun 216. This can be done at a factory where gun 216 is manufactured or a job site. Key pad 234 is mounted to nail gun 216 to facilitate data entry by the tool user. A user employs key pad 234 to enter a nailing pattern or select a preprogrammed nailing pattern.

20 In this embodiment, nail gun 216 operates with a guide system that provides for identifying a coordinate position. These guide systems include the guide wire system shown in Figure 5 and the dual laser system shown in Figure 4. Nail gun 216 operates as described above for tool 10 in Figures 4 and 5 to identify when gun 216 is oriented in line with a position where a nail 25 is to be driven into a work piece. In gun 216, component controller 16 enables the gun's firing mechanism when location detector 14 indicates gun 216 is oriented in line with a desired nail target.

Those of ordinary skill in the art understand that as patterns for nailing can be established, the gun can also be programmed for "keep out" areas. 30 On the keep out areas, the gun would not fire, even if the trigger were pulled. The keep out areas could be programmed by positioning the nail gun on the periphery of the keep out area and pushing a button on key pad 234 —

programming the position of the nailing gun as determined by guide detector 12 and location detector 14.

In other versions of nail gun 216, a memory in gun 216 records every position where a nail is fired into a work piece — making nail gun 216 self-auditing. The nailing pattern can be verified without the use of an inspector by downloading the nail pattern from the memory of nailing gun 216. Such self-auditing might be quite helpful in situations where precise nailing patterns are desirable. A related example is a similar application of placing rivets on an aircraft wing.

10 Figure 10 depicts an embodiment of the present invention with nail gun 302 employing rolling sensor 304 as a guide system. One example of rolling sensor 304 is track ball mechanism 100 shown in Figure 6. Nail gun 302 includes the functionality and design described for tool 10 in Figure 6, as well as key pad 306. Nail gun 302 allows a user to select a nail spacing pattern 15 and only enables the gun's firing mechanism once rolling sensor 304 indicates the nailing gun is in the right position. Nail gun 302 determines its orientation by evaluating the guide signals from rolling sensor 304 using guide detector 12 and location detector 14, as described above with reference to Figure 6. Location detector 14 then compares the detected orientation to the desired 20 nail target. When nail gun 302 is in the desired position, indicator set 20 (Fig. 6) lights LED 308 to inform the user to pull the gun's trigger.

When nailing a piece of plywood or sheet rock with nail gun 302, a user can hold onto the trigger of gun 302, and slide gun 302 in a straight line. Nail gun 302 only fires in exact spacing increments, such as for example, every six 25 inches. In another embodiment, a stud sensing system 310, which is known in the art, is added to nail gun 302. Nail gun 302 does not fire unless appropriately aligned with a stud underneath. In another implementation, nail gun 302 includes electrical voltage sensor 312 so that gun 302 does not fire if the nailing pattern interrupts an electric wire.

2. Jigsaw Embodiments

Figures 11 and 11A depict jigsaw 404 in use with laser system 402 to ensure that jigsaw 404 follows a cutting line defined by laser beam 408. Jigsaw 404 includes the functionality and design of tool 10 described in Figure 5 3, and laser system 402 is the same as laser system 50 in Figure 3. Jigsaw 404 employs photo diode detector array 406 to detect laser beam 408 in the same way guide detector 12 was described to operate in Figure 3. Jigsaw 404 also includes location detector 14 to determine the orientation of jigsaw 404 and determine whether an orientation adjustment is necessary.

10 In one implementation, jigsaw 404 is a scroll type jigsaw with manual handle 410, which can direct the orientation of blade 412. Component controller 16 in saw 404 also controls the orientation of blade 412 — driving a steering motor (not shown) attached to blade 412 to rotate blade 412 about its longitude axis 414. When jigsaw blade 412 starts to drift off the center line of 15 laser beam 408, location detector 14 detects this occurrence and instructs component controller 16 to adjust the orientation of blade 412. Component controller 16 drives the steering motor to rotate blade 412 — keeping blade 412 in line with laser beam 408.

20 3. Circular Saw Embodiments

Figure 12 shows circular saw 502 operating in conjunction with laser system 504 to ensure that saw 502 follows a predetermined cutting line defined by laser beam 508. Circular saw 502 and laser system 504 are the same as tool 10 and laser system 50 from Figure 3. Circular saw 502 25 includes photo diode detector array 506 to serve as guide detector 12. Photo diode detector array 304 is mounted on the front of a circular saw 502, such that the position of beam 508 relative to saw 502 is detected. Array 506 combines with location detector 14 to determine the orientation of saw 502 and whether any orientation corrections need to be made for the saw's blade 30 to stay in line with laser beam 508.

In operation, a user provides a manual push to propel saw 502. When the orientation of saw 502 needs to be adjusted, location detector 14 signals

component controller 16. In one implementation, component controller 16 drives motor steering mechanism 510 to change the orientation of the saw's blade to come in line with laser beam 508.

In an alternate embodiment, a blade velocity gauge (not shown) 5 replaces motor steering mechanism 510 to implement angular velocity ripple. One half of the blade has teeth bent to the right, and the other half of the blade as teeth bent to the left. The velocity gauge responds to an orientation correction signal from component controller 16 by increasing the rotational speed of the blade for half a rotation. The increased speed steers the saw 10 toward the direction of the teeth with enhanced speed.

In another implementation, alignment pistons 512 and 514 are employed in lieu of motor steering mechanism 510 and the above-described velocity gauge. Pistons 512 and 514 are positioned between circular saw 502 and handle 516, which a user employs to propel and steer saw 502. 15 Component controller 16 issues signals to control alignment pistons 512 and 514 — causing pistons 512 to 514 to adjust their lengths to bring the saw blade in line with laser beam 508. Examples of pistons 512 and 514 include pneumatic pistons and hydraulic pistons for a large saw arrangement. Alternatively, pistons 512 and 514 are mechanical pistons, extending or 20 retracting in response to a rack and pinion arrangement driven by a motor.

#### 4. Router Embodiments

Figure 13 shows router 601 in use with lasers 602a and 602b to ensure the proper orientation of the router's cutting head. Router 601 includes the functionality and design of tool 10 in Figure 4, and laser systems 602a and 602b are the same as laser systems 60 and 62 in Figure 4. Photo diode detector array 604 is mounted on router 601 to serve as guide detector 12. Array 604 combines with location detector 14 to receive laser beams 603a and 603b from lasers 602a and 602b and determine the orientation of router 30 601. As described with reference to Figure 4, location detector 14 determines the orientation of router 601 in terms of an absolute position, such as a (x, y)

coordinate. Based on the router's orientation, location detector 14 determines whether any tool adjustments are needed.

In one implementation, location detector 14 instructs component controller 16 to adjust the vertical displacement of the router's cutting head, 5 based on the detected orientation. Component controller 16 directs the operation of a motor that moves the cutting head along a vertical axis. A memory in router 601 stores relief patterns, such as those used for carvings or cabinet face panel configurations. The vertical displacement of the cutting head is set to follow the desired depth of cut for each position in the relief 10 pattern. This allows a user to simply move router 601 back and forth across a work piece, while router 601 automatically adjusts the height of the router cutting head. In a further embodiment, location detector 14 sends control signals to indicator set 20 — showing a user the direction to steer router 601 for a selected relief pattern by illuminating lights 606.

15 In another embodiment, router 601 only employs a single laser system, such as laser system 602a. Router 601 uses array 604 and location controller 14 to control lights 606, so a user receives steering directions for keeping router 601 in line with laser beam 603a.

Figure 14 shows router 702 in use with guide wires 704 and 706 to 20 achieve the same functionality as described above for router 601. Router 702 has the same functionality and design as router 10 in Figure 5, and guide wires 704 and 706 operate the same as guide wires 84 and 86 in Figure 5.

D. Tool Alignment, Depth Detection, and Leveling

25 Figure 15 shows tool 802 with depth detector 812 and alignment detector 804. In Figure 15 tool 802 is shown as a drill. In alternate embodiments, however, tool 802 can be a variety of different tools, such as a nail gun. In one embodiment, tool 802 includes the functionality and design described for tool 10 in Figures 1-7. In alternate embodiments, tool 802 only 30 includes a subset or none of the functionality described for tool 10 above.

Alignment detector 804 is attached to the head of the drill 804 and provides laser light grid 806. Grid 806 appears on a work piece as a set of

perpendicular lines, resembling a tic-tac-toe grid, when face 799 of alignment detector 804 is parallel to the surface of the work piece. Alignment detector 804 is attached to drill 802 so the tic-tac-toe grid appears when the drill bit in drill 802 is normal to the surface of the work piece. Grid 806 includes parallel

5 lines 805 and 807, which are perpendicular to parallel grid lines 801 and 803. A set of laser planes extending from alignment guide 804 form laser lines 801 and 803. Another set of laser planes extending from alignment guide 804 form laser lines 805 and 807.

When drill 802 is not normal to the work piece surface, lines 805 and

10 807 do not appear perpendicular to lines 801 and 803. When this occurs, the user adjusts the orientation of drill 802 until lines 801 and 803 are parallel to each other, lines 805 and 807 are parallel to each other, and lines 801 and 803 are perpendicular to lines 805 and 807. Those skilled in the art will

15 recognize that patterns other than a tic-tac-toe grid can be employed in alternate embodiments.

Figure 15A shows a side view of hardware employed in alignment detector 804 to form grid 806. Figure 15B shows a side view of the same hardware in Figure 15A rotated by 90 degrees. Alignment detector 804 includes laser sources 810, 1810, 2810, and 3810 and optical elements 809, 20 1809, 2809, and 3809 mounted in a housing (not shown). In one embodiment, laser sources 810, 1810, 2810, and 3810 are laser diodes, and optical elements 809, 1809, 2809, and 3809 are holographic elements. Those skilled in the art recognize that alternate components can be employed. For example, optical elements 809, 1809, 2809, and 3809 can be cylindrical lenses in alternate embodiments. Laser diodes 810, 1810, 2810, and 3810 deliver laser beams 811, 1811, 2811, and 3811 to holographic plates 809, 1809, 2809, and 3809, respectively. Laser beams 811, 1811, 2811, and 3811 are schematic representations of the actual laser beams from diodes 810, 1810, 2810, and 3810. Those skilled in the art understand that laser diodes 30 810, 1810, 2810, and 3810 each output a diverging laser beam that impacts a substantial portion or all of holographic plates 809, 1809, 2809, and 3809, respectively.

Holographic plates 809, 1809, 2809, and 3809 convert laser beams 811, 1811, 2811, and 3811 into a first laser plane set including converging laser planes 801 and 803, and a second laser plane set including converging laser planes 805 and 807. The planes from optical element 2809 is not shown in Figure 15A, and the plane for optical element 809 is not shown in Figure 15B. Planes 801, 803, 805, and 807 form laser lines 801, 803, 805, and 807, respectively, on the incident surface of a work piece. Alignment detector 804 can be aligned so that planes 801, 803, 805, and 807 are incident on a surface either before or after the location where the planes intersect.

Methods for designing and fabricating holographic plates, such as plates 809, 1809, 2809, and 3809, are well known in the art. In alternate embodiments, alignment detector 804 includes collimating lenses between lasers 810, 1810, 2810, and 3810 and holographic plates 809, 1809, 2809 and 3809, respectively.

In further embodiments, planes 801 and 803 originate from their respective optical elements as diverging planes. This is also true for planes 805 and 807. The term converging is used in this application to explain planes' initial orientation to each other at one point in space. As those skilled in the art recognize, converging planes, like those shown in Figures 15A and 15B, begin to diverge from each other after intersecting. In yet another embodiment, spinning lasers can be employed to create laser lines 801, 803, 805, and 807.

In other implementations, fewer than four laser sources are employed to generate laser beams 811, 1811, 2811, and 3811. For example, one laser source can be employed with multiple beam splitters, or other mechanisms for dividing a laser beam, to form beams 811, 1811, 2811, and 3811. Numerous combinations of laser sources and beam dividing mechanisms are possible.

Depth detector 812 (Figure 15) determines the work piece depth reached by the bit on drill 802. Depth detector 812 is mounted to rotating chuck 814 of drill 802. Depth detector 812 determines when a preset depth

has been reached and illuminates light 816 on drill 802 to inform the user that the appropriate depth had been obtained.

In one embodiment, depth detector 812 includes a sonar system similar to those employed in camera systems or a pin diode system.

5 Alternatively, in conjunction with detector 812, a device is provided in drill 802 to measure the revolutions per minute of drill chuck 814. Computational means, such as a microprocessor, can then be provided to calculate the depth of the drilling action and the orientation of the drill bit relative to the work surface by knowing the angular speed and position of chuck 814.

10 Figures 16 and 17 show an alternate embodiment of a depth detector 813 that can be attached to tool 802. The depth detector shown in Figures 16 and 17 is mounted to tool 802 on a stationary portion of the tool, like the way alignment detector 804 is attached to tool 802. Depth detector 813 generates laser patterns, as shown in Figures 16A and 17A, to indicate the depth of tool

15 802.

Depth detector 813 includes laser sources 815, 1815, 2815, 3815, 4815, and 5815 and optical elements 819, 1819, 2819, 3819, 4819, and 5819 mounted in a housing (not shown). In one embodiment, laser sources 815, 1815, 2815, 3815, 4815, and 5815 are laser diodes, and optical elements

20 819, 1819, 2819, 3819, 4819, and 5819 are holographic plates. Those skilled in the art recognize that other components can be employed for laser sources and optical elements, as explained above with regard to Figures 15, 15A, and 15B. Laser diodes 815, 1815, 2815, 3815, 4815, and 5815 supply laser beams 817, 1817, 2817, 3817, 4817, and 5817 to holographic plates 819,

25 1819, 2819, 3819, 4819, and 5819, which generate a set of laser planes. When the laser planes impact on a work piece surface they form patterns that correspond to the distance between depth detector 813 and the work piece. Figures 16A and 17A show example laser patterns. In further embodiments, depth detector 813 employs optical elements other than holographic plates,

30 such as cylindrical lenses, to generate the patterns in Figures 16A and 17A. In other embodiments, depth detector 813 includes a collimating lens between the laser sources and optical elements.

Laser pattern 820 in Figure 16A includes a first set of lines 828, 830 and 832 and a second set of lines 826, 824, and 822. Depth detector 813 generates pattern 820 by emitting two sets of converging laser planes. As shown in Figures 16 and 16A, the three planes in the first set are parallel to each other and form lines 828, 830, and 832 when they impact on a work piece. The three planes in the second set are parallel to each other and form lines 826, 824, and 822 when they impact on a work piece. Planes in the first set forming lines 828, 830, and 832 converge with the planes in the second set forming lines 826, 824, and 822.

5 10 As drill 802 is lowered into the work piece, the lines from the first set of laser planes and the lines from the second set of laser planes begin to move towards each other and eventually overlap, as shown in pattern 834. The tool operator determines the depth reached by tool 802, based on the laser line pattern produced by depth detector 812. In alternate embodiments, the 15 appearance of lines 828, 830, and 832 are differentiated from the appearance of lines 826, 824, and 822. For example, one set of laser lines is generated as dashed lines.

In Figure 17A, pattern 840 from depth detector 813 includes a set of horizontal lines 848, 850, and 852 and a set of vertical lines 842, 844, and 846. Each line in pattern 840 comes from a laser plane from depth detector 813 impacting a work piece surface. As shown in Figure 17, depth detector 813 includes holographic plates 819, 1819, 2819, 3819, 4819, and 5819 to convert laser beams 817, 1817, 2817, 3817, 4817, and 5817, respectively, into the following: a first set of planes that form horizontal lines 848, 850, and 852 on a work piece and a second set of laser planes that form vertical lines 842, 844, and 846 on a work piece. The first set of planes is angled to converge with the second set of planes.

The resulting pattern on the work piece informs a tool operator of the depth reached by tool 802. Pattern 841 shows how the set of vertical lines 30 overlaps with the set of horizontal lines as depth detector 813 moves closer to the work piece. In one embodiment, depth detector 813 is designed so a vertical line and horizontal line form a cross when tool 802 reaches a

predefined depth. In further implementations, demarcations other than lines can be employed, such as crosses or stars.

Figure 18 shows a level detector 860 employed on a tool in one embodiment of the present invention. In one implementation, level detector 860 is included on a tool with the functionality described above for tools 10 and 802. In other implementations, level detector 860 is included on a tool with a subset or none of the functionality described for tools 10 and 802. In some embodiments, level detector 860 is included in a leveling tool that only performs level detection operations.

Level detector 860 includes laser sources 862 and 1862 providing laser beams 864 and 1864 to optical elements 866 and 1866, respectively. The components of laser detector 860 are mounted in a housing (not shown). In one implementation, laser sources 862 and 1862 are laser diodes, and optical elements 866 and 1866 are holographic plates. Those skilled in the art recognize that other components can be employed, as described above with reference to Figures 15, 15A, and 15B. In alternate implementations, a collimating lens is inserted between holographic plates 866 and 1866 and laser diodes 862 and 1862, respectively. Holographic plates 866 and 1866 convert laser beams 864 and 1864 into converging laser planes 870 and 868, respectively. Planes 868 and 870 intersect along line 872.

In operation, level detector 860 is suspended above the surface of a work piece, such as the top of a counter. In one implementation, level detector 860 is adjustably mounted on a tool, so its position with respect to a work surface can be modified. Level detector 860 is positioned so intersection line 872 is incident on the work piece surface. As shown in Figure 18A, this creates single laser line 872 on the work piece surface — showing the tool user that the surface is level in the area where line 872 appears.

If the work piece surface is not level, two laser lines appear on the surface. In Figure 18A, single laser line 872 diverges into laser line segments 868 and 870 — indicating a surface area section that is not level with the area where line 872 appears. The diverging diagonal portions of laser line

segments 868 and 870 indicate that the work piece surface is sloped. The parallel portions of laser line segments 868 and 870 indicate that the work piece surface is level, but offset from the area where line 872 exists.

Level detector 860 in Figure 18 has broad applicability. In one instance, level detector 860 is mounted on a laser guide, as described above, to ensure that a rotating laser plane provided by the guide is perpendicular to a surface. In this application level detector 860 is mounted to the laser device so intersection line 872 appears on the target surface, or a parallel surface, when the laser plane is perpendicular.

10 In another embodiment, level detector 860 is employed when shimming a counter top. The counter is shimmed, until only intersection line 872 appears on the counter. If multiple lines 868 and 870 appear additional wedges are added under the counter surface. Leveling a counter top in multiple directions can be achieved by using multiple level detectors or a modified version of level detector 860. The modified version includes multiple level detectors, like the one shown in Figure 18, to produce laser leveling signal's from multiple sides of the device.

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Level detector 860 can also be used to determine whether a wall is plumb, by placing the detector at the wall's base or top. If only intersection line 872 appears, the wall is plumb. If multiple diverging laser lines appear, the wall is not plumb.

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#### E. Tool Control System

Figure 19 illustrates a high level block diagram of general purpose computer system 900. System 900 may be employed in embodiments of the present invention to provide the functionality for guide detector 12, location detector 14, component controller 16, communications port 18, and indicator set 20. System 900 may be employed on tool 10 or remote from tool 10, but in either circumstance is considered to be part of tool 10. Accordingly, computer system 900 may be employed for performing a number of processes, including those described above with reference to Figures 1-14.

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Computer system 900 contains processing unit 905, main memory 910, and interconnect bus 925. Processing unit 905 may contain a single microcontroller, single microprocessor, or a plurality of microcontrollers or microprocessors for configuring computer system 900 as a multi-processor system. Processing unit 905 is employed in conjunction with a memory or other data storage medium containing application specific program code instructions to implement the functionality of guide detector 12, location detector 14, and component controller 16.

Main memory 910 stores, in part, instructions and data for execution by processing unit 905. If a process, such as the processes described with reference to Figures 1-14, is wholly or partially implemented in software, main memory 910 can store the executable instructions for implementing the process when the computer is in operation. For example, main memory 910 can store program code instructions employed by guide detector 12, location detector 14, and component controller 16. In one implementation, main memory 910 includes banks of dynamic random access memory (DRAM) as well as high speed cache memory.

In one implementation, computer system 900 further include mass storage device 920, peripheral device(s) 930, portable storage medium drive(s) 940, input control device(s) 970, graphics subsystem 950, and output display 960. In alternate implementations, computer system 900 does not include all of the devices shown in Figure 19.

For purposes of simplicity, all components in computer system 900 are shown in Figure 19 as being connected via bus 925. However, computer system 900 may be connected through one or more data transport means in alternate implementations. For example, processing unit 905 and main memory 910 may be connected via a local microprocessor bus, and mass storage device 920, peripheral device(s) 930, portable storage medium drive(s) 940, and graphics subsystem 950 may be connected via one or more input/output busses.

Mass storage device 920 is a non-volatile storage device for storing data and instructions for use by processing unit 905. Mass storage device 920

can be implemented in a variety of ways, including a magnetic disk drive or an optical disk drive. In software embodiments of the present invention, mass storage device 920 stores the instructions executed by computer system 900 to perform processes such as those described with reference to Figures 1-14.

5 Portable storage medium drive 940 operates in conjunction with a portable non-volatile storage medium to input and output data and code to and from computer system 900. Examples of such storage mediums include floppy disks, compact disc read only memories (CD-ROM), memory sticks, and integrated circuit non-volatile memory adapters (i.e. PC-MCIA adapter). In

10 10 one embodiment, the instructions for enabling computer system 900 to execute processes, such as those described with reference to Figures 1-14, are stored on such a portable medium, and are input to computer system 900 via portable storage medium drive 940.

Peripheral device(s) 930 may include any type of computer support device, such as an input/output interface, to add additional functionality to computer system 900. For example, peripheral device(s) 930 may include a communications controller, such as a network interface card or integrated circuit, for interfacing computer system 900 to a communications network or point-to-point links with other devices. Instructions for enabling computer system 900 to perform processes, such as those described with reference to Figures 1-14, may be downloaded into the computer system's main memory 910 over a communications network. Computer system 900 may also interface to a database management system over a communications network or other medium that is supported by peripheral device(s) 930.

25 25 Input control device(s) 970 provide a portion of the user interface for a user of computer system 900. Input control device(s) 970 may include an alphanumeric keypad for inputting alphanumeric and other key information, a cursor control device, such as a mouse, a track ball, stylus, or cursor direction keys. In order to display textual and graphical information, computer system 30 900 contains graphics subsystem 950 and output display 960. Output display 960 can include a cathode ray tube display or liquid crystal display. Graphics

subsystem 950 receives textual and graphical information, and processes the information for output to output display 960.

The components contained in computer system 900 are those typically found in general purpose computer systems. In fact, these components are

5 intended to represent a broad category of such computer components that are well known in the art.

The process steps and other functions described above with respect to embodiments of the present invention may be implemented as software instructions. More particularly, the process steps described with reference to

10 Figures 1-14 may be implemented as software instructions. For one software implementation, the software includes a plurality of computer executable instructions for implementation on a general purpose or application specific computer system. Prior to loading into a computer system, the software instructions may reside as encoded information on a computer readable  
15 medium, such as a magnetic floppy disk, magnetic tape, and compact disc read only memory (CD - ROM). In one hardware implementation, circuits may be developed to perform the process steps and other functions described herein.

The foregoing detailed description of the invention has been presented  
20 for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. The described embodiments were chosen in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art  
25 to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.